07 July 2020

CAMP2EX Data Archiving and Processing Documentation – TAMMS (3-D Winds)

Instrument: TAMMS (Turbulent Air Motion Measurement System)

Staff:

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Platform: NASA P-3

Primary Measurements:

- Wind Speed (+/- 0.6 m/s)
- Wind Direction (+/- 5 deg)
- Horizontal Wind Components (u and v) (+/- 0.6 m/s)
- Vertical Wind Speed (+/- 0.15 m/s)
- Static Air Temperature (+/- 0.5 deg C)
- Static Pressure (+/- 0.25 mb)

Post-Mission Calculated Parameters:

- Sensible Heat Flux
- Turbulent Kinetic Energy
- Momentum Fluxes

Raw Data Collection Rate:

- 50-100 hz

Data Archive Rate:

- 20 hz

ARCHIVE FILE HEADER:

48,1001
Thornhill, Lee
NASA Langley
Fast in-situ 3-D wind and temperature measurements from the NASA P-3B
CAMP2EX
1,1
2019,08,03,2020,04,14

0.05
Time_mid,Secs after midnight,Time of acquisition
11
1,1,1,1,1,1,1,1,1,1,1
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Latitude_deg, deg, Platform_Latitude_insitu_None, GPS Latitude
Longitude_deg, deg, Platform_Longitude_insitu_None, GPS Longitude
gpsALT_m,m, Platform_AltitudeEllipsoid_insitu_None, GPS WGS84 Altitude Reference
Pitch_deg, deg, Platform_PitchAngle_insitu_None, Pitch Angle
Roll_deg, deg, Platform_RollAngle_insitu_None, Roll Angle
Tstat_degC, degC, Met_StaticPressure_insitu_None, Static Temperature
WSPD_ms-1, ms-1, Met_WindSpeed_insitu_None, Horizontal Wind Speed
WDIR_deg, deg, Met_WindDirection_insitu_None, Horizontal Wind Direction
U_ms-1, ms-1, Met_UWindSpeed_insitu_None, E-W Horizontal Wind Speed
V_ms-1, ms-1, Met_VWindSpeed_insitu_None, N-S Horizontal Wind Speed
w_ms-1, ms-1, Met_WWindSpeed_insitu_None, Vertical Wind Speed
0
23
****
NASA Langley Fast Response Wind and Temperature Data (2019 CAMP2EX) field campaign

PI_CONTACT_INFO: Kenneth.L.Thornhill@nasa.gov
PLATFORM: NASA P-3B aircraft
LOCATION: Latitude, Longitude, and Altitude included from the P-3B Flight Management System
ASSOCIATED_DATA: N/A
INSTRUMENT_INFO: Flagged data are due to missing data or non straight and level flight
DATA_INFO: Winds are valid for straight and level flight, take caution when using data in turns/ascents/descents
DATA_INFO: Horizontal winds have the pressure correction and the heading offset applied
UNCERTAINTY: horizontal winds +/- 0.2 m/s, vertical winds +/- 0.1 m/s
ULOD_FLAG: -7777
ULOD_VALUE: N/A
LLOD_FLAG: -8888
LLOD_VALUE: N/A
DM_CONTACT_INFO: Lee Thornhill (Kenneth.L.Thornhill@nasa.gov)
PROJECT_INFO: CAMP2EX 2019
STIPULATIONS_ON_USE: This is FINAL data, please consult PI with questions about use
OTHER_COMMENTS: none
REVISION: R0
R0: FINAL DATA - calibrations, corrections, and time lags have been applied
****

Measurement Principles:

In general, measuring the winds from an aircraft requires the following parameters

- Pressure
- Acceleration
- Aircraft attitude
- Aircraft Position
- Aircraft Velocity

The ambient wind measurement requires the determination of two velocity vectors: the velocity of air with respect to the aircraft and the velocity of the aircraft with respect to the Earth. The sum of those two (large numbers) is the velocity of the wind with respect to the Earth (smaller number).

The P-3B TAMMS includes fast-response flow-angle and temperature sensors; inertial navigation (INS) and flight management systems (FMS) to provide the aircraft's position, speed and attitude; and a PC-based data acquisition system with appropriate interfaces to record all the incoming signals. The flow-angle system includes five, flush-mounted pressure-ports installed in a cruciform pattern in the aircraft radome to provide angle of attack (vertically-aligned ports) and side-slip (horizontally aligned ports) measurements (Brown et al, 1983). Corresponding fast-response (20-Hz), high-precision pressure transducers are placed as close as possible to the pressure ports to minimize delays and errors. Pitch and yaw maneuvers, speed variations and reverse headings are performed periodically during deployments to verify system operation and calibration and validate derived mean horizontal-wind vectors. Three dimensional winds are computed from the full air motion equations (Lenschow, 1986). The vertical platform velocity components are computed from a third-order baro-loop, which limits the errors in vertical acceleration by bounding the doubly integrated vertical acceleration by the pressure altitude (Lenschow, 1986). Ambient air temperature measurements needed to determine true air speed and heat flux are made with a Rosemount Model 102 non-deiced total air temperature sensor with a fast response platinum sensing element (E102E4AL). Derived measurements of U, V, W, and T are archived at 20 Hz resolution.

Calibrations Required and Reasoning Why:

There are several tests that need to be done in the air and cannot be done on the ground. They include:

- Static Pressure Error (Pressure Deficit) – along track reverse heading
- Heading Offset – cross track reverse headings
- Static Air Temperature
- Speed Variations
- Sideslip Maneuvers

Static Pressure Error (Pressure Deficit)

Where the effects of the fuselage on the oncoming air is minimized, the total pressure is equal to the free-stream static pressure plus the dynamic (impact) pressure, i.e. $p_{total} = p_{static} + q_c$. The blunt shape of the aircraft causes the streamlines of the oncoming air to diverge rapidly, creating differences between the measured pressure and the free-stream pressure. This difference permeates throughout the winds equations.

Total pressure is conserved at any point along the aircraft body, i.e. $p_{total} = p' + q'_c$. where the prime denote the local value and not the free-stream true value. The static pressure error is defined as $\Delta p = p' - p_{static}$. Thus the equation for the total pressure is defined as $p_{total} = p_{static} + \Delta p + q'_c$ and for impact (dynamic) pressure $q'_c = q_c - \Delta p$.

For blunt fuselages, the term Δp can be substantial. The presence of the fuselage causes an increase in the static pressure and a decrease in the local dynamic pressure.

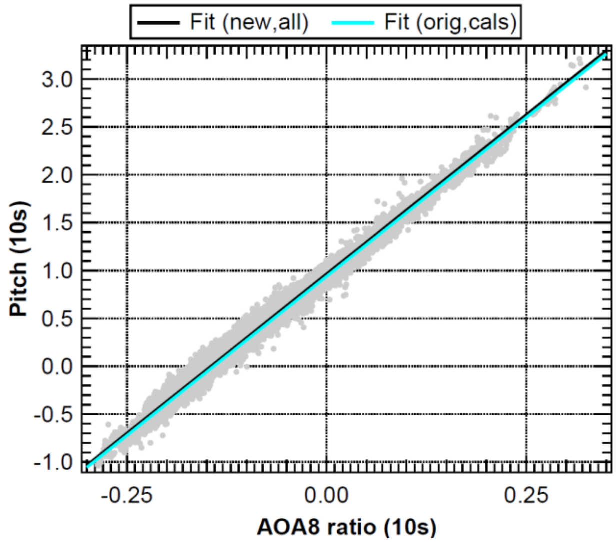
Characterizing the pressure defect is not easy and can be done by several methods including tower flybys and trailing cones. When that is not possible (as in our case), the pressure defect can be characterized by repeated reverse headings in the along wind direction. By flying as close as possible in the along wind direction, error in the heading are minimized and the error caused by the pressure defect is maximized.

Reverse Headings:

For this maneuver the plane should fly at a constant altitude and heading, in a homogenous airmass above the boundary layer. The maneuver modulates the airspeed and sideslip errors, since the along track winds are dominated by the true airspeed, showing errors in the pressure deficit term, while the cross track winds are dominated by the sideslip angle and shows error in the sideslip coefficients. Tracks should be lined up in the cross-track and along-track direction with respect to the wind direction. Tracks should be about 4-5 min in each direction. If the calibrations are good the winds should be aligned.

Speed Variations:

Speed variations help determine the angle of attack slope and offset and are crucial for computing accurate vertical winds. To do a reverse heading: Fly at a constant altitude and heading in a stable clear airmass. Vary the aircraft indicated airspeed from minimum to maximum speeds, holding speeds constant for 60-120s at each step. For the P-3B, we generally varied the airspeed in 20-30 kts steps somewhere between 190 to 310 kIAS depending on the altitude and aircraft weight. The maneuver modulates angle of attack (AOA) and pitch due to the relation between lift to AOA and airspeed. The result of all the ORACLES speed variations is shown in the plot below. It shows excellent agreement between the pitch and angle of attack measurements.



<u>Sideslip Maneuvers (Yaw, Crabbing, or Skids)</u>
Fly at a constant altitude and heading, and, while holding the heading constant, yaw the aircraft left 5 degrees and then right 5 degrees. Do this several times, takes 3-5 minutes. The maneuver is used to determine the slope for the sideslip angle. The true heading, horizontal aircraft velocities, and the sideslip parameters are modulated, and errors show up as a periodic variation in the horizontal wind calculation. The sideslip offset needs to be adjusted until the cross-track wind components are equal in the reverse heading maneuvers.

Data Processing:

Data processing is done via the program IGOR by Wavemetrics (wavemetrics.com). The raw data is put into an Excel spreadsheet and then read into the IGOR program for processing, analysis, and archive creation. That way the raw data remains untouched and unaltered. The raw data is read in and gotten ready for processing (i.e. raw voltages converted to engineering units) and all data converted to standard units for processing (i.e. knots converted to m/s) and then data is computed for both dry and moist conditions and the moist data is used to compute the 3-D winds via the full winds equations. The data is then cleaned up to take out bad data periods and the archive files are created. The IGOR program allows for graphing and data analysis and is a very good program to use for analysis and programming. The modules for the processing and are commented in the individual modules. There is one master IGOR file for processing all 3 years of ORACLES data to ease processing needs.

Data Validation: - done through repeated calibrations to build up better and better statistics

Data Revisions:

- 2018:
  - <u>R0</u>: FINAL DATA: included all time lags and calibration results to date
  - TAKE CAUTION ON USING MEAN VALUES IN NON STRAIGHT and LEVEL FLIGHT. Improved platform velocities for U, V, & W based on using Litton-251 data

Raw Data Recorded (between 1 and 100 hz, depending on the parameters):

- IWG1: broadcast by NSRC, gives aircraft and state parameters at 1hz and used for reference and initial QC
- ANALOG:
  - 10 analog channels which are measurements of
  - Total Air Temp, Dew Point, Vertical Acceleration, and transducer pressures for the radome and 858Y 5-hole ports
- ARINC-429:
  - GPS: GPStime, ALT, LAT, LON, IAS, TAS, TRK, gSPD, Pitch, Roll
  - FMS: GPStime, Palt, TAS, LAT, LON, gSPD, THG, TRK, WSPD, WDIR, VNS, VEW
  - IRS: LAT, LON, TRK, HDG, WSPD, WDIR, PITCH, ROLL, pHDG, Vacc, NSvel, EWvel
  - MADT: Pstat, Ptot, Qc, Palt, Mach
  - ADC: Palt, BAROalt, Mach, IAS